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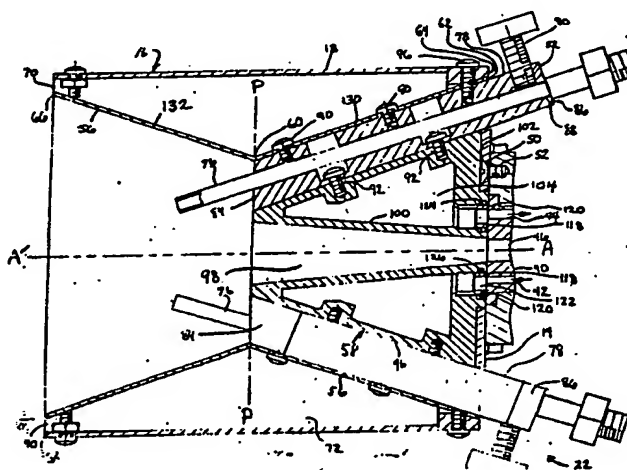


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(54) Title: APPARATUS AND METHOD FOR APPLYING PLASMA FLAME SPRAYED POLYMERS**(57) Abstract**

An apparatus and method for applying plasma flame sprayed polymers is provided which permits the application of a thin coating of heat fusible material onto substrate material. The apparatus is used with a conventional plasma generator (12) whereby materials such as nylon or other synthetic polymers may be injected into the plasma stream to melt the powder without overheating it. The apparatus includes a central water-cooled nozzle (58), surrounded by an open co-axial flow area within a barrel (16). The polymer is evenly distributed on the substrate due to the co-axial flow of the plasma stream and air drawn through the flow area. A source of vacuum (20) connected to the apparatus (10) draws fumes generated by the melted polymers into an opening surrounding the bore (98) at the front of the barrel (16), whereby the vacuumed gases may be filtered. The apparatus (10) may be used in a method of applying plasma flame sprayed polymer compositions to a surface.



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APPARATUS AND METHOD FOR APPLYING
PLASMA FLAME SPRAYED POLYMERS

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Background of the Invention

1. Field of the Invention

An apparatus for rapidly applying a polymer coating to a variety of surfaces through plasma flame spraying is provided, enabling the user to work in relative safety and achieve a smooth, uniform coating. The apparatus hereof is particularly concerned with a hand-held device for plasma flame spraying a variety of polymers whereby a surface such as wood, fibrous glass reinforced synthetic resin, or even cardboard may be sprayed in close proximity to the front of the barrel of the apparatus without damaging the surface or exposing the operator to potentially toxic fumes resulting from the melted polymer. In its preferred method aspects, the invention involves applying a protective coating to a surface such as a boat hull by providing a electric arc, directing a gas stream through the arc thereby heating the gas stream, injecting a powdered polymer into the gas stream at a location downstream from the arc so as to melt the powder without overheating the same, and then applying the melted mixture to the surface to be coated.

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2. Description of the Prior Art

Plasma flame spraying has proven to be a highly efficient and effective method of applying heat fusible materials to a variety of heat resistant surfaces. Plasma is an extremely hot substance consisting of free electrons, positive ions, atoms and molecules. Although it conducts electricity, it

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1 is electrically neutral. Plasma is usually
generated at temperatures in the vicinity of 15,000
degrees Centigrade by the passage of a gas through
5 an electric arc. In typical plasma spraying systems, a selected inert gas, such as argon or nitrogen, flows between an anode and a cathode. An electrical arc is generated between the anode and cathode, both heating and propelling a heat fusible material carried with the gas. The movement of the
10 gas between the anode and cathode effectively lengthens the path of the arc, causing more energy to be delivered to the arc. The plasma may issue from the nozzle at subsonic to Mach II speeds, with a flame of intense brightness and heat resembling an
15 open oxy-acetylene flame.

It may be readily appreciated that the intense heat associated with the plasma stream and the rapid flow of the plasma through the gun presents a highly efficient means of melting a heat
20 fusible material and spraying it on a target surface. The plasma flame spray guns previously developed have been principally designed to apply powdered ceramics or metals which have high melting temperatures. These materials are typically
25 injected at or near the arc to achieve the instantaneous melting required when the plasma stream is flowing at sonic or near sonic speeds. Despite the intense heat generated at the arc, the temperature of the plasma gas stream drops rapidly across the intervening distance between the electrode and the
30 target surface. This drop is a function of gas enthalpy, energy absorption by the powdered material, and work distance.

It has become increasingly popular to
35 attempt to apply synthetic polymers by the plasma

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1 flame spray method. Flame sprayed polymer powders
are lighter in mass and have a much lower melting
point than ceramics or metals. As a result, the
high temperatures of the arc tend to "burn" the
5 polymers rendering the resulting coating unsuitable.
Various plasma spray devices have been developed
for use with polymers, such as that of U.S. Patent
No. 3,676,638, which discloses a nozzle whereby
powder is fed into the plasma gas stream downstream
10 from the arc. These prior plasma spray devices have
~~been~~ limited in the rate of application due to the
low arc power settings necessary to avoid "burning"
the polymer, and have had a tendency to produce a
somewhat uneven coating with splattering and dan-
gerous and inefficient overspray.

15 Nonetheless, the durability and density of
plasma sprayed polymer coatings have produced a
demand for devices which can effectively apply these
coatings. In contrast to painted polymer coatings;
20 which require a great deal of surface preparation
and wear rapidly, plasma flame sprayed polymer
coatings provide a wear-resistant coating of high
density with a high bond strength generated as a
result of the high velocity impact of the molten
composition onto the target surface. In addition,
25 only a nominal amount of grit blasting to slightly
roughen the surface and remove any surface contami-
nation is necessary to prepare the surface for
plasma flame spraying. However, certain polymer
compositions have heretofore been difficult to use
30 in hand held operation because of the toxic fumes
released by the molten polymer in the plasma stream.
Further, prior apparatus made it difficult to
prevent the plasma gas stream from scorching the
surface during application. The high heat of the
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1 plasma stream in close proximity to the user also
posed a safety hazard in the event a plasma gas
stream were to be inadvertently directed at the user
5 or another person. Because of the high heat
generated by the plasma gas stream, the target
surface remained hot after the deposit of the
coating, resulting in additional release of toxic
fumes into the environment.

10 Summary of the Invention

The problems outlined above are in large
measure solved by the present invention which pro-
vides an apparatus for plasma flame spraying poly-
mers on a variety of target surfaces by providing a
15 cooled, laminar flow plasma gas stream with a mini-
mum of turbulence. The apparatus includes a conven-
tional plasma flame generator and a novel barrel for
cooling the plasma gas stream, providing a plasma
gas stream having a minimum of turbulence between a
20 nozzle and the target surface, and introducing a
polymer in the plasma gas stream.

The invention hereof includes a fluid-
cooled plasma flame generator, a barrel, and means
for mounting the barrel to the plasma flame gene-
rator. The barrel includes a fluid-cooled nozzle
25 through which the plasma gas stream passes upon
exiting the plasma flame generator. An open, co-
axial airflow area surrounds the nozzle and permits
air to flow from the rear of the barrel to the front
of the barrel in the same direction and substan-
30 tially co-axial with the flow of the plasma gas
stream. Powder introduction tubes are mounted
exterior to the nozzle for introducing polymer,
usually in powdered form, into the plasma gas stream
downstream from the nozzle.

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More particularly, the invention hereof includes a frustoconical shaped nozzle which is provided with a central bore and an interior which is adapted to receive a fluid coolant with a water-cooled plasma flame generator. The nozzle, and the barrel of which it is one component, are mounted to the plasma flame generator by an adaptor plate which permits the exchange of coolant between the generator and the nozzle. The nozzle is thus cooled both by the circulation of coolant on the interior thereof, as well as the flow of air over the exterior surface.

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The barrel is provided with an hourglass-shaped interior wall, with the waist of the hourglass-shaped interior wall lying in the same plane as the front end of the nozzle. The posterior margin of the interior wall abuts the posterior margin of the exterior wall to form an air seal therebetween. In contrast, the diameter of the anterior margin of the interior wall is somewhat less than the anterior margin of the exterior wall, defining an annular space therebetween. A vacuum source may be attached to the barrel to both cool the target surface and draw fumes and polymer which has splattered off the target surface into the space between the interior and exterior walls of the barrel to a separate filtering device. Toxic vapors resulting from the melting of particular polymers are thereby captured, maintaining a safe environment for the operator.

Because of the nozzle design and the provision for coaxial flow of air and plasma gas, the plasma gas stream exits the nozzle with a minimum of turbulence and remains substantially laminar as it travels to the target surface. The sur-

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1 rounding air cools the stream and permits the intro-
duction of the polymer outside the nozzle, substan-
tially in the atmosphere. The plasma gas stream is
5 thereby sufficiently cooled to enable coating of
combustibles such as even cardboard or fibrous glass
reinforced plastic at a distance of four inches (10
centimeters). Being able to operate the apparatus
so closely to the target surface minimizes the
10 danger to other workers and permits accurate and
uniform coating. It also improves the effectiveness
of the vacuum in cooling the target surface and
preventing vapor and particle loss to the atmos-
phere, in effect maintaining a separate environment
for operation of the apparatus.

15 The exterior wall of the barrel also acts
as a shroud to enclose the open arc, thereby pre-
venting eye burn to the operator or other workers in
the vicinity. The absence of a "flame" extending
beyond the barrel improves the safety of the device.

20 One particular polymer composition which
may be used in connection with this invention and a
method for applying it is shown, for example, in my
U.S. Application Serial No. 193,805, (attorney's
Docket No. 19615), filed concurrently herewith and
25 entitled Protective Coating for Boat Hulls and
Method of Applying the Same, the disclosure of which
is incorporated herein by reference.

30 These and other advantages will be readily
apparent to those skilled in the art from the dis-
closure recited herein.

Brief Description of the Drawing

35 Figure 1 is a side elevational view of the
apparatus for applying plasma flame sprayed poly-
mers;

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Fig. 2 is a top plan view of the apparatus shown in Fig. 1;

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Fig. 3 is a front elevational view showing the annular space between the interior and exterior walls of the barrel;

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Fig. 4 is a rear elevational view showing the adapter plate mounted to the nozzle at the rear of the barrel, and a pair of powder introduction tubes for introducing powder into the plasma gas stream;

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Fig. 5 is a front elevational view of the fluid cooled plasma flame generator hereof, and in particular a PLASMADYNE Model SG-100 with the cover plate removed to expose coolant exchange ports in the anode, and a control handle coupled thereto; and

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Fig. 6 is an enlarged, horizontal sectional view along line 6-6 of Fig. 1, showing the nozzle, carrier tubes, coolant circulation path and interior and exterior barrel walls.

Detailed Description of the Drawing

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Referring now to the drawing, an apparatus for applying plasma flame sprayed polymers 10, in accordance with the invention, includes a plasma flame generator 12, adaptor plate 14 and barrel 16. Barrel 16 is provided with a substantially cylindrical outer wall 18, and vacuum connection 20. As shown in Figs. 1-3, 4 and 6, a pair of carrier block assemblies 22 extend from the posterior of the barrel and are mounted therein.

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The plasma flame generator 12 shown and described herein is a PLASMADYNE Model SG-100, which operates at power levels up to 80 kilowatts using argon, argon/hydrogen or argon/helium as the plasma gas. The Model SG-100 is water-cooled, with a water

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1 and power inlet connection 24 at the center rear of
the generator 12 and a water and power outlet con-
5 nection 26 located therebeneath. The water and
power outlet line 28 extends from the front of the
generator rearward through graspable handle 30.
Handle 30 is provided with trigger button 32 for
initiating the plasma stream, and trigger button 34
10 for initiation of powder feed. The PLASMADYNE Model
SG-100 is further provided with a plasma gas con-
nection 36 for connection with the argon, argon/-
hydrogen or argon/helium feed line. Powder tube 38
extends beneath the generator for passage of powder
near the electrodes within the generator for use of
the apparatus with ceramic or metallic powders.

15 The conventional PLASMADYNE Model SG-100
is provided with a cover plate for preventing the
escape of cooling water which circulates through the
generator and particularly the anode 40, as shown in
Fig. 5. A series of water supply ports 42 provide a
20 flow of water in a path toward barrel 16, while a
series of larger water return ports 44 carry the
water coolant toward the water and power outlet line
28, the water coolant carrying excess heat generated
by the arc. In the center of the copper anode 40, a
25 plasma orifice 46 permits the plasma gas stream to
exit the generator and enter the barrel 16.

Barrel 16 is joined to generator 12 by
adaptor plate 14. Adaptor plate 14 is in the nature
of a flat, annular copper disc provided with a
30 central opening 48 in front of anode 40. The adap-
tor plate is provided with three equally spaced
countersunk holes 50 with mounting screws 52 in-
serted therethrough into generator 12. A second

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1 series of three holes 54 are provided for mounting the barrel 16 to the adaptor plate 14.

Referring now to Figs. 3 and 4, barrel 16 includes outer wall 18, vacuum connection 20, carrier block assembly 22, inner wall 56 and nozzle 58. The inner wall 56 is hourglass-shaped, being composed of two opposed frustoconical members joined at the waist 60 of the hourglass shape thereby created. The diameter of the exterior of the posterior margin 62 of the inner wall 56 is substantially the same as the interior diameter of the posterior margin 64 of the outer wall 18, thereby forming an effective fluid-tight air seal between the posterior margin 64 of the outer wall 18 and the posterior margin 62 of the inner wall 56.

In contrast, the outside diameter of the anterior margin 66 of the inner wall 56 is sufficiently less than the inside diameter of the anterior margin 68 of the outer wall 18, thereby defining an annular opening 70 between the inner wall 56 and exterior wall 18. Except at the posterior margins 64 and 62, outer wall 18 and inner wall 56 are spaced apart, defining an airway 72 therebetween. The airway 72 communicates with vacuum connection 20 by an opening in the outer wall 18 at the junction of the vacuum connection 20 and the outer wall 18, for the passage of air drawn therethrough by a vacuum source.

Carrier block assemblies 22 are mounted on opposite sides of barrel 16 between inner wall 56 and nozzle 58. The two carrier block assemblies 22 lie in approximately the same plane as each other, and occupy a portion of the otherwise continuous open coaxial airflow area 74 which substantially surrounds the nozzle 58. Each carrier block

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1 assembly includes a copper powder introduction tube
76, a carrier block 78 and a threaded tightening
5 screws 80. As may be seen in Fig. 6, the tightening
screws 80 extend through tapped openings 82 in the
carrier blocks 78, thereby permitting the tubes 76
to be removed from the carrier blocks 78 but still
ensuring that the tubes 76 remain properly posi-
tioned during operation.

10 The carrier blocks 78 are tapered at their
anterior ends 84 and posterior ends 86 as shown in
Figs. 3 and 4, thereby minimizing the turbulence of
the air as it flows past the carrier blocks 78 into
the open coaxial flow area 74. An aperture 88
15 extends through the carrier blocks 78, each aperture
being in the same horizontal plane and the horizon-
tal plane bisecting the nozzle 58. The apertures
88 converge from the posterior of the barrel 16
toward the anterior of the barrel 16, each at an
angle from 12 to 20 degrees and preferably 18
20 degrees from the flow axis A-A' of the plasma gas
stream.

As may be seen in Fig. 6, the powder
introduction tubes 76 are of a sufficient length
that the tubes 76 extend forward of the carrier
25 block 78 and nozzle 58. The front of the nozzle 58,
anterior end 84 of the carrier block 78, and waist
60 of the inner wall 56 all lie in the same plane P.
Plane P is substantially normal to plasma gas stream
flow axis A-A'. Thus, the powder introduction tubes
76 are located exterior to the nozzle 58, extend
30 beyond the nozzle 58, and direct a carrier gas and
powdered polymer stream in a direction convergent
with the plasma gas flow axis A-A' so that the
polymer is introduced through the tubes 76 into the
plasma gas stream at a location downstream from the
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1 nozzle 58. The plasma gas stream is thus exposed to
the atmosphere before intersection with the powdered
polymer. The tubes 76 are threaded at their pos-
5 terior end for connection to a supply line carrying
a carrier gas such as nitrogen or argon and a poly-
mer powder.

The carrier blocks 78 are secured by
screws 90, 92 to the inner wall 56 and nozzle 58 and
thus serve to join the nozzle 58, carrier block
10 assemblies 22, and inner wall 56. Inasmuch as outer
wall 18 and inner wall 56 are joined to the carrier
block 78 adjacent their posterior margins 64, 62 by
screws 96, the nozzle 58, carrier block assemblies
22, inner wall 56 and outer wall 18 substantially
15 form the barrel 16.

The nozzle 58 is a hollow, copper frusto-
conical member having an exterior jacket surface 96
tapering inwardly with its center along flow axis
A-A'. The exterior diameter of the exterior jacket
20 96 decreases along the plasma gas stream flow from A
to A', with A being at the posterior of the barrel
16. The inner wall 56 and the exterior jacket 96
define the coaxial airflow area 74 therebetween.
The co-axial flow area 74 is substantially annular
25 in cross-section adjacent nozzle 58 and is adapted
to communicate air drawn through the open area
between nozzle 58 and posterior margin 62 by the
plasma gas stream to the open area at the front of
the barrel 16.

In contrast, the nozzle 58 is provided
30 with a central bore 98 defined by interior jacket
100 of the nozzle, the diameter of the bore increas-
ing in a direction along the plasma gas stream flow
axis from A to A'. The bore 98 is frustoconical in
configuration, with the axis of the bore 98 coinci-
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dent with the plasma gas stream flow axis A-A'. The bore 98 thus tapers outwardly in the direction of the plasma gas stream as defined by the interior jacket 100 of the nozzle 58.

The rear wall 102 of the nozzle 58, together with the exterior jacket 96 and the interior jacket 100 define a substantially open chamber 104 to receive fluid coolant therein. Water flows into the chamber 104 from water supply port 42 in the anode 40 through accesses 106, 108 and 110 at the rear of the nozzle 58. Water or other fluid coolant enters chamber 104, circulates at random and accumulates heat therein, and is forced out through accesses 106, 108 and 110 to water return ports 44 in the anode 40 by additional water furnished through water supply ports 42.

Support arms 112, 114 and 116 interconnect rear wall 102 and interior jacket 100, providing structural rigidity and maintaining the bore 98 in proper alignment. Anode 40 is provided with lips 118 and 120 to provide a channel for the cooling water and enter recessed area 122 to form a seal between the nozzle 58 and anode 40. Silicon rubber O-rings 124, 126 ensure that the seal thus created remains watertight. A raised ring portion 128 of rear wall 102 mates with adaptor ring 14 and anode 40. The difference between the outside diameter of interior jacket 100 and the inside diameter of ring portion 128 defines accesses 106, 108 and 110.

In the preferred embodiment, the upstream frustoconical portion 130 of the inner wall 56 is convergent in the direction of flow of the plasma gas stream along the axis from A to A', at an angle of approximately 20 degrees from A-A'. The down-

stream frustoconical member 132 of the hourglass-shaped interior wall 56 is divergent in the direction of plasma gas flow along axis from A to A', at an angle of approximately 25 degrees from A-A'. The exterior jacket 96 of the nozzle 58 is convergent in the direction of flow of the plasma gas stream along the axis from A to A' at an angle of 20 degrees from A-A'. The interior jacket 100 of the nozzle 58 is divergent in the direction of flow of the plasma gas stream from A to A' at an angle of 5° from A-A'.

The apparatus is assembled by mounting adaptor plate 14 on generator 12 with screws 52. Barrel 16 is then mounted on adaptor plate 14 by three allen bolts 134 inserted through holes 54 spaced around the exterior of the adaptor plate 14 and threaded into corresponding threaded holes 136 around the exterior of the nozzle 58. Necessary cables and hoses are then connected at the locations corresponding to the fittings described hereinabove.

Polymers may be sprayed utilizing the apparatus described herein by the method described as follows.

A polymer such as nylon is prepared in pelletized forms of a size of approximately 325 mesh (120 microns) and placed in a powder feeder such as a Plasmatron Model 1251 powder feeder. A source of argon or other carrier gas is connected with the powder feeder and then the carrier gas - powder feed line is connected with appropriate fittings to powder introduction tube 76. A second source of gas, also preferably argon, provides the source for the plasma gas and is routed through, for example, a Plasmadyne Model powder feeder and thence to the plasma generator 12, with connections at plasma gas connection 36. Cooling water is supplied from a

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1 suitable water source, with additional pressure
supplied by a suitable water pump. The water hose
is coaxial with a control cable and power supply
5 cable connected at water and power inlet connection
24 by suitable coaxial hoses. The water and power
return line returns water from the plasma generator
to the heat exchanger. The control cable is routed
through a control console, such as a Plasmatron
100 Model 3700, into an auxiliary powder feed control,
such as a Plasmatron Model 3700-200. Power is
supplied by a suitable source of 40 kilowatt powder,
such as a Plasmatron Model PS-61N. Finally, a
vacuum source, such as a vacuum pump is connected by
a hose to vacuum connection 20. When water, power,
15 plasma gas, carrier gas and powder, and vacuum are
supplied to the apparatus, it is ready for operation.

Preferred techniques for applying a polymer coating composition include the steps of providing a high velocity flow (i.e., about Mach I or above) of a gas such as pure argon; passing gas transversely through an elongated high wattage electric arc for heating the gas and converting a portion thereof to the plasma state through plasma generator 12; introducing the powdered coating composition into the gas downstream from nozzle 58 through powder introduction tubes 76 for melting the powder without overheating the powder; directing the flow of the coating composition and associated gas into substantially one direction for minimizing overspray and misting of the composition; and spraying said melted composition onto a target surface to be coated.

In a more preferred method, the plasma gas stream exits a nozzle 58 and draws with it air
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1 provided from an open, co-axial flow area 74 prior
to the introduction of the polymer composition into
the plasma gas stream. More preferably, the
5 powdered composition is introduced into the gas
stream in a downstream direction and at an angle
from about 12 to 20 degrees to the direction of flow
of the plasma gas stream from A to A'; and most
preferably the powdered composition is injected in a
10 downstream direction at an angle of about 18 degrees
to that of the plasma gas stream so as to minimize
vortex formation within the stream and minimize the
overspray associated with vortex formation. Also
more preferably, the powder is injected at a dis-
15 tance of about 6 to 10 inches downstream from the
arc (the arc being defined as the point of energy
transfer between an anode and a cathode) so as to
minimize overheating of the composition and so as to
insure that the composition reaches maximum velocity
for a corresponding maximum bond strength with the
20 surface to be coated; and more preferably, injecting
the composition into the gas stream at a location of
about from 8.5 to 9 inches downstream from the arc
so as to achieve the proper molten state of the
composition and a particle velocity favoring inner
25 atomic bonding of the composition with the surface
to be coated.

If injection of the powdered composition
is made either through a high wattage arc or closely
adjacent thereto, the composition will be overheated
and rendered useless. If a lower wattage arc is
30 employed so as to generate a temperature low enough
to permit injection of the powder either through the
arc or adjacent thereto, then the application rate
permitted by the arc will be so low as to make large
scale application economically infeasible. Thus,

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1 introduction of the powdered composition substan-
tially downstream from the arc is advantageous to
5 achieve an economically feasible, high volumetric
rate application technique. Also, injection of the
powder downstream from the arc permits increased arc
temperature, which in turn permits adequate heating
10 of increased flows of gas thereby permitting ade-
quate melting and particle velocity for increased
powder flow rates. Yet further, the higher arc
temperature and injection of the polymer powder
downstream from the nozzle enables the simultaneous
15 spraying of polymers and ceramics or metals when a
carrier gas and metal or ceramic powder hose is
connected at powder tube 38. To achieve the high
volumetric application rates of, for example, poly-
amide coatings, the arc used in the method of the
20 present invention has a preferred power level of 20
to 40 kilowatts and an associated gas temperature at
the arc of approximately 12,000 to 30,000 degrees
Centigrade. More preferably, the arc has a power
level of 28 kilowatts and an associated gas tempera-
25 ture at the arc of approximately 22,500° Centigrade.
The plasma gas stream is then cooled by the appara-
tus 10 hereof so that by the time the plasma gas
stream flowing on axis A-A' has reached the junction
with the carrier gas and powdered composition
30 exiting from the powder introduction tube 76, the
temperature of the plasma gas stream has dropped
down to approximately 250 to 800 degrees Centigrade
while travelling at 5,000 to 7,000 feet per second.
Gases useful as plasma gas in this invention include
35 H₂, N₂, He, Ar and combinations thereof. The coat-
ings made from the use of that apparatus 10 hereof
when applied using the application techniques of the
present invention provide coatings having applica-

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1 tion rates, densities and bond strengths substan-
tially greater than that of coatings applied by
conventional polyamid application techniques such as
fluidized bed dipping, acetyline flame spraying and
5 electrostatic spraying.

5 The plasma spray method of the present
invention further involves vacuuming toxic fumes
in the ambient air from a periphery of the plasma
gas stream adjacent the surface to be sprayed and
into annular opening 70. By vacuuming the toxic
10 fumes, the operator and the surrounding atmosphere
are not subject to the toxic fumes generated during
heating of certain polymer compositions which would
otherwise escape into the atmosphere. Vacuumed
15 gases are oil filtered to remove the toxic gas
fumes. The fumes are drawn into annular opening 70
and airway 72, then exit the apparatus 10 through
vacuum connection 20 into a suitable vacuum hose and
eventually to a filtering device to remove the toxic
20 gas fumes and organic acid vapors. The vacuum pulls
at a rate of at least 10 inches of water at 85 cubic
feet per minute and preferably 150 cubic feet per
minute.

25 The following example sets the preferred
preparation of a powdered composition in accordance
with the present invention, together with typical
steps involved in application of the coating.

EXAMPLE

30 A premelt powdered coating composition
such as Nylon 11 is prepared in pelletized form of a
size of approximately 325 mesh (120 microns).

35 A supply of pure argon gas, at a flow rate
of 1.42 cubic feet per minute (cfm) at 50 psi is
passed through an electric arc of the plasma

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generator 12 hereof having a power level of 18 kilowatts. The arc substantially heats the gas and causes some of the gas to be converted to the plasma state. This heated stream is then cooled as it moves away from the arc by passing through water cooled anode 40, fluid cooled nozzle 58, and a coaxial flow of air surrounding the plasma gas stream as the mach 1 plasma stream draws air through coaxial airflow area 74. The powdered polymer composition is then injected by use of a pressurized carrier gas such as nitrogen or argon through powder introduction tube 76 as described hereinabove into the heated gas stream at a location about 8.5 inches downstream from the arc and about 6 inches downstream from the rear wall of the nozzle, and at an angle of about 18 degrees to that of the general flow of the plasma gas stream along flow axis A-A'. The polymer composition and the plasma gas stream then combine to properly melt the composition and impart a substantial velocity onto the melted composition. The gas and composition are then passed further downstream together in a substantially uniform direction so as to minimize overspray and then are sprayed directly onto a target surface such as an aluminum boat hull so as to form a film coating of the composition thereof. The film coating is then allowed to cool and bond with the surface.

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Claims:

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1. An apparatus for applying plasma flame sprayed polymers comprising:

- a. A fluid-cooled plasma flame generator
- b. Mounting means attached to the plasma flame generator
- c. A barrel mounted to the plasma flame generator by said mounting means, said barrel including:

- i. A fluid cooled nozzle defining a bore for the passage of a plasma gas stream therewithin, said nozzle being located within said barrel
- ii. Structure defining an open, coaxial airflow area located radially outward from the nozzle and within said barrel, said airflow area permitting the flow of air through the barrel in a direction substantially co-axial with the plasma gas stream; and
- iii. Means for introducing a polymer into the plasma gas stream downstream from said nozzle.

2. An apparatus for applying plasma flame sprayed polymers as set forth in Claim 1, wherein means are provided for the circulation of the fluid coolant between the plasma flame generator and the nozzle.

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3. An apparatus for applying plasma flame sprayed polymers as set forth in Claim 1, wherein the bore of the nozzle is tapered, with the diameter of the bore expanding in the direction of flow of the plasma gas stream.

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4. An apparatus for applying plasma flame sprayed polymers as set forth in Claim 1, wherein the barrel is provided with an inner wall and an outer wall, said walls being spaced apart and defining a first space therebetween, and there being a second space between the inner wall and the nozzle defining said open co-axial flow area.

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5. An apparatus for applying plasma flame sprayed polymers as set forth in Claim 4, wherein the exterior of the nozzle is tapered toward the downstream end thereof, with the diameter of the exterior of the nozzle decreasing in the direction of flow of the plasma gas stream.

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6. An apparatus as set forth in Claim 5, wherein the inner wall is constructed of upstream and downstream frustoconical members, said members being joined at a waist to present an hourglass shaped inner wall.

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7. An apparatus as set forth in Claim 6, wherein said plasma gas stream flows along one axis, the waist of the two frustoconical members defining a plane, said plane being substantially normal to the flow axis of the plasma gas stream.

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8. An apparatus as set forth in Claim 7, wherein the plane extends across the downstream end of the nozzle.

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9. An apparatus as set forth in Claim 6, wherein the exterior wall of the barrel is of substantially the same diameter as and is joined together with the posterior margin of the upstream frustoconical member to form a fluid-tight seal therebetween, the anterior margin of the downstream frustoconical member and the outer wall defining an annular opening therebetween, said outer wall further including means for connecting a vacuum source thereto.

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10. An apparatus for applying plasma flame sprayed polymers as set forth in Claim 1 including a plurality of said polymer introduction means, each of said means being oriented so that the axis of said polymer introduction means intersects a flow axis of the plasma gas stream at a point downstream from said nozzle.

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11. An apparatus for applying plasma flame sprayed polymers as set forth in Claim 1, wherein said apparatus is provided with means for enabling the simultaneous plasma flame spraying of polymers and powdered ceramics or powdered metals.

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12. An apparatus for applying plasma flame sprayed polymers as set forth in Claim 1, wherein the polymer introduction means is located exterior to the nozzle.

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13. A method of applying a polymer composition coating to a target surface comprising the steps of:

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providing an electric arc;

directing a high velocity gas stream through said arc thereby heating said gas stream and converting a portion thereof to the plasma state;

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discharging the gas stream from a nozzle;

introducing a polymer composition into said gas stream at a location downstream from the nozzle to melt said polymer composition without overheating said polymer composition; and

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applying said melted polymer composition to a surface.

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14. The method of Claim 13 wherein the gas is selected from a group consisting of Ar, N₂, H₂ and He.

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15. The method of Claim 13 wherein the flow of said gas and said polymer composition are directed in a substantially uniform direction following injection of said composition into said gas stream.

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16. The method of Claim 13 wherein the heated gas stream is exposed to the atmosphere prior to introduction of said polymer composition.

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17. The method of Claim 16 wherein the surrounding atmosphere is drawn past the nozzle to flow co-axially with said gas stream.

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18. The method of Claim 13, further comprising vacuuming the ambient air from a periphery of the plasma gas stream adjacent the surface to be sprayed.

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19. The method of Claim 13 wherein said arc has a power level of 20 to 40 kilowatts.

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20. The method of Claim 13 wherein said gas stream is heated to a temperature of about 12,000° to 30,000°C.

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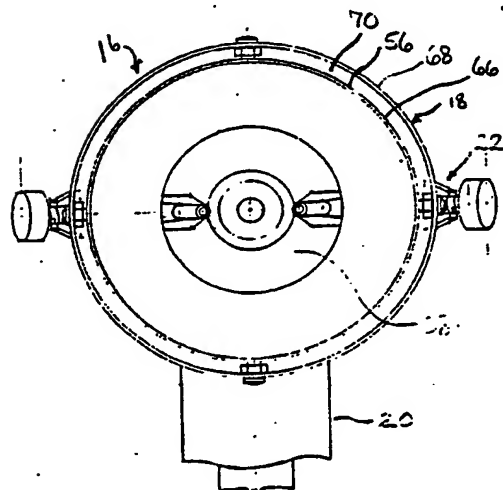
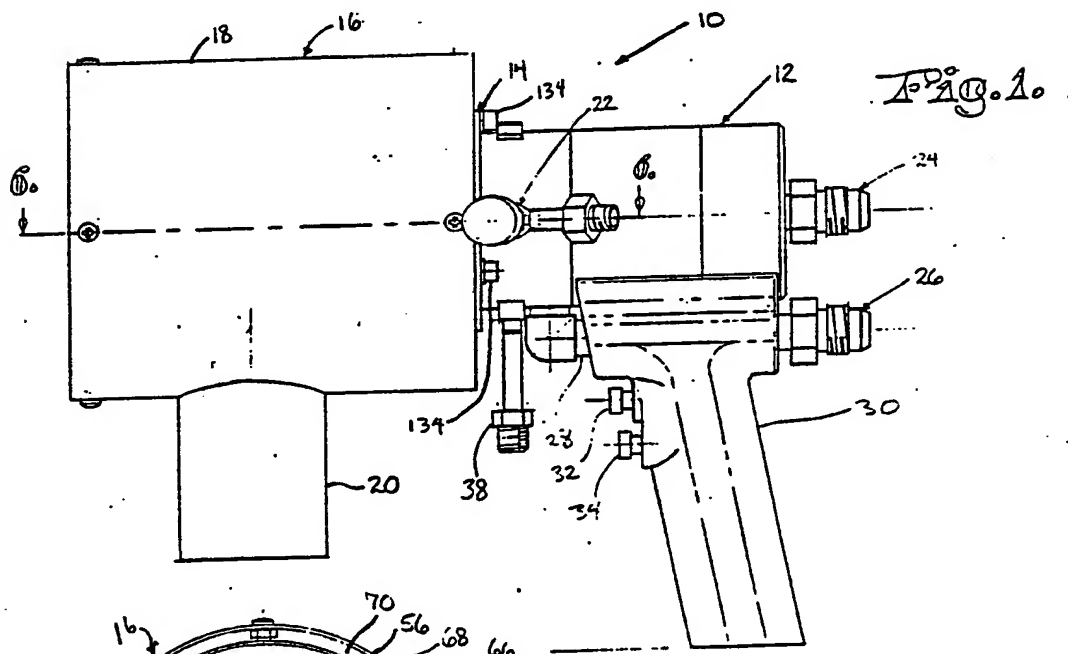
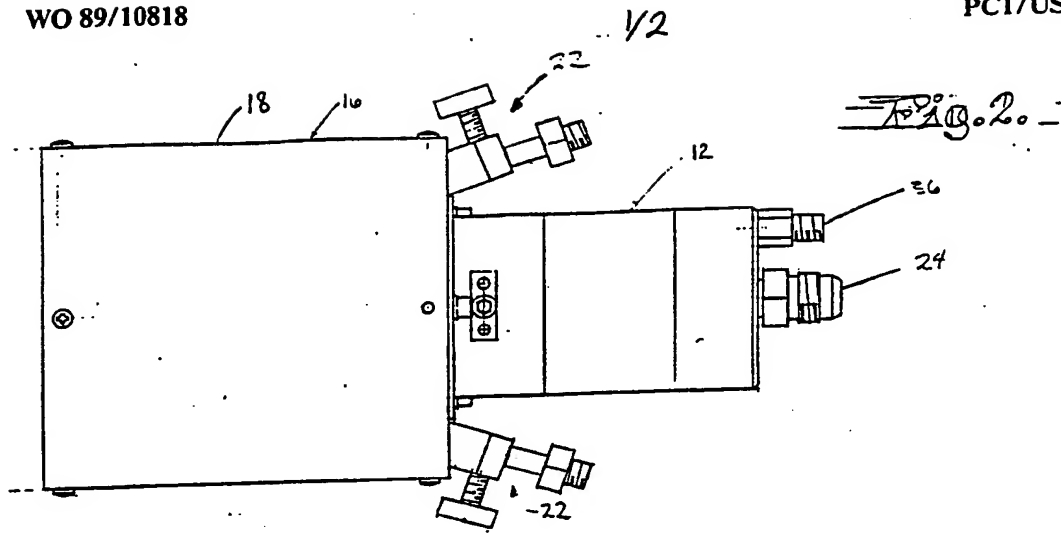
21. The method of Claim 20, wherein said melted polymer composition reaches a maximum temperature of about 250° to 800°C.

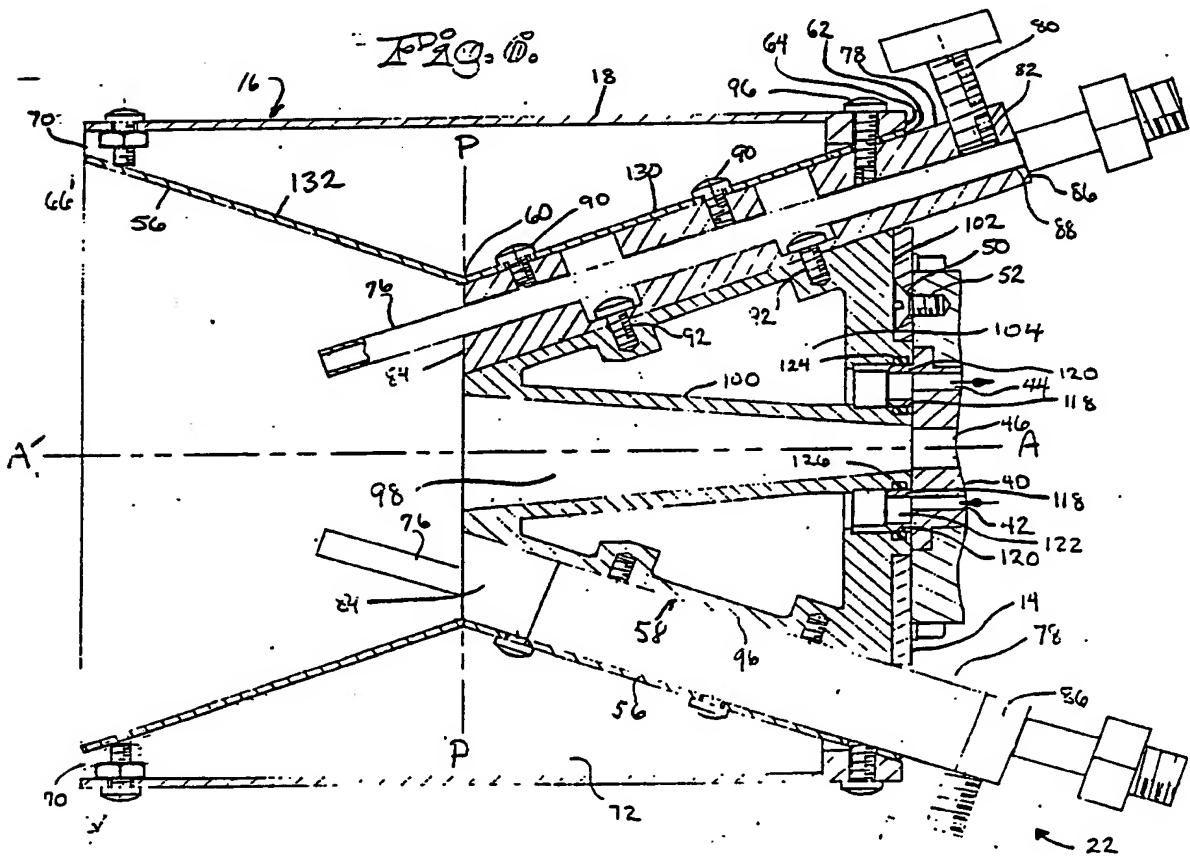
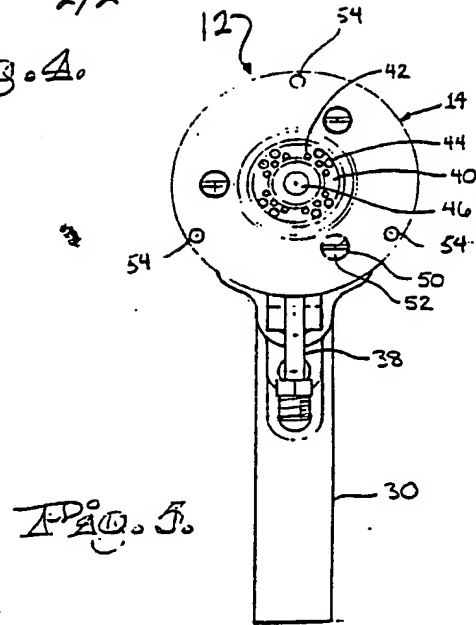
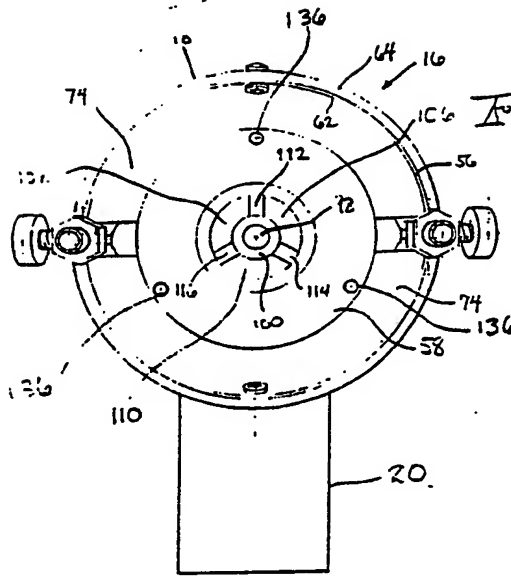
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INTERNATIONAL SEARCH REPORT

International Application No. PCT/US89/02053

I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all) ⁶		
According to International Patent Classification (IPC) or to both National Classification and IPC IPC (4): B23K 9/00, B05D 1/00 U.S. CL.: 219/121.47, 76.16, 121.5, 121.49, 427/34		
II. FIELDS SEARCHED		
Minimum Documentation Searched ⁷		
Classification System	Classification Symbols	
U.S.	219/121.47, 76.16, 121.5, 121.49, 121.51, 75 427/34	
Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in the Fields Searched ⁸		
III. DOCUMENTS CONSIDERED TO BE RELEVANT ⁹		
Category ¹⁰	Citation of Document, ¹¹ with indication, where appropriate, of the relevant passages ¹²	Relevant to Claim No. ¹³
Y	US, A, 4,370,538 (BROWNING) 25 January 1983 See entire document.	1-12
X	US, A, 4,694,990 (KARLSSON et al) 22 September 1987, See entire document.	13-21
Y	US, A, 4,625,094 (MARHIE et al) 25 November 1986, See entire document.	1-12
A	US, A, 3,591,759 (STAND) 6 July 1971 See entire document.	1-12
A	US, A, 3,740,522 (MUEHLBERGER) 19 June 1973 See entire document.	1-12
P, A	US, A, 4,818,837 (PFENDER) 4 April 1989 See entire document.	1-21
<div style="display: flex; justify-content: space-between;"> <div style="width: 45%;"> <p>¹⁰ Special categories of cited documents:</p> <p>"A" document defining the general state of the art which is not considered to be of particular relevance</p> <p>"E" earlier document but published on or after the international filing date</p> <p>"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)</p> <p>"O" document referring to an oral disclosure, use, exhibition or other means</p> <p>"P" document published prior to the international filing date but later than the priority date claimed</p> </div> <div style="width: 45%;"> <p>"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention</p> <p>"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step</p> <p>"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.</p> <p>"&" document member of the same patent family</p> </div> </div>		
IV. CERTIFICATION		
Date of the Actual Completion of the International Search 05 August 1989 International Searching Authority ISA/US	Date of Mailing of this International Search Report <div style="font-size: 1.2em; font-weight: bold; text-align: center;">01 SEP 1989</div> Signature of Authorized Officer M. H. PASCHALL	